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ABSTRACT

The purpose of this study was to integrate logical and empirical techniques into a procedure to develop and validate hierarchical curriculum structures and to demonstrate use of the procedure by applying it during the development of an Individualized Mathematics Curriculum. A procedure was designed and tested using 72 first-grade students. This testing resulted in content related findings which suggested modifications in the Individualized Mathematics Curriculum, and procedural findings which led to refinements in the procedure being tested. (Author/SD)

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THE INTEGRATION OF LOGICAL AND EMPIRICAL PROCEDURES FOR HIERARCHICALLY STRUCTURING AN INDIVIDUALIZED CURRICULUM

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INTRODUCTION

The purpose of this study was to integrate logical and empirical techniques into a methodology for the development and validation of hierarchical curriculum structures in individualized curricula. Its use was demonstrated by applying it to a portion of the Individualized Mathematics (IM) Curriculum (1971) which is used by primary grade (1-3) children. The general method of individualization on which the IM Curriculum is based has six components (Glaser and Nitko, 1971).

1. Outcomes of learning are specified in terms of the behavioral manifestations of competence and the conditions under which it is to be exercised.

2. Detailed diagnosis is made of the initial state of a learner entering a particular instructional situation.

3. Educational alternatives are provided that are adaptive to the classifications resulting from the initial student educational profiles.

4. As the student learns, his performance is monitored and repeatedly assessed at longer or shorter intervals appropriate to what is being taught.

5. Instruction and learning proceed in a cybernetic fashion, tracking the performance and selections of the student.

6. The system collects information in order to improve itself, and inherent in the system's design is its capability for doing this. (pp. 631-632)

The IM Curriculum is organized into units, each of which is comprised of instructional objectives defined in terms of student behaviors. This paper reports the results obtained from applying the procedure that was developed by the author, to two of the IM units to illustrate its use in one situation.

A Selected Review of the Literature
Related To Sequencing and Validating Techniques

Many instructional designers, developers and learning psychologists have expressed the need to organize the components of a task (e.g. the objectives within a unit) in some hierarchical fashion (e.g. Gagne, 1962; Briggs, 1968; Resnick, 1967; Glaser, 1973). The reasoning is that children learn some components more readily than others and/or that some skills are pre-requisite to others. Their position has been supported by the results of experiments that investigated variables, such as the time needed to complete the instructional program, the errors made in the program, and the level of achievement attained on a criterion test (Niedermeyer, Brown and Sulzen, 1969; Brown, 1970; Uprichard, 1970; Phillips and Kane, 1973).

Two types of approaches that have been suggested for sequencing objectives are logical analysis [e.g. "task analysis" (Gagne, 1962) and "component analysis" (Resnick, 1967)], and empirical analysis [e.g. "scalogram analysis" (Guttman, 1944, 1950)].

The case for logically ordering curriculum objectives was made by a number of curriculum designers. Lindvall and Cox (1969) stated that

> Sequencing and organizing objectives are key steps in the design of a program of individualized instruction. Some type of order is essential for determining how far advanced each pupil is within the curriculum for planning his next learning experiences, and for monitoring his progress (p. 163).

Gagne (1962) found that the proper ordering of subordinate or prerequisite objectives "mediate positive transfer to higher-level tasks (p. 363)." Resnick (1973) likened this transfer to that found in the small steps used in programmed instruction.

Recommendations for using empirical research have been made by curriculum designers, program evaluators, and subject matter experts (Briggs, 1968; Boozer, 1970; Resnick, 1967; Boozer and Lindvall, 1971). Essentially, their point of view is that evidence based on the performance of the learner should play a major part in the validation of theoretically derived curriculum hierarchies.

METHODOLOGY

Procedure

The procedure developed by the author integrates a logical structuring technique, Gagne's "task analysis" (1962), with an empirical validation method, Lingoes' "multiple scalogram analysis" (1963). Multiple scalogram analysis is an adaptation of Guttman's (1944, 1950) technique. A scale, as defined by Guttman (1950), is a set of items where each person's specific item responses are reproducible from his score. That is, by arranging the items in order from the least difficult to the most difficult, a person will pass the items to a certain point, and fail the remaining items. From a person's score, such as 15, we would then know that s/he has answered the first 15 items of the test correctly.

Guttman's technique was advantageously adapted by Lingoes (1963) in a computer program that analyzes students' responses to dichotomous items in order to create (or validate) a scale. In order for all of the items submitted to be arranged in a single scale by multiple scalogram analysis, certain statistical criteria must be met. If a single scale does not exist among all of the items, i.e. all of the criteria are not met, the procedure will suggest scales consisting of fewer items. In addition, the coefficient

of reproducibility is reported for each scale produced by multiple scalogram analysis. (The coefficient of reproducibility indicates the degree to which a set of items approximates a perfect scale.) The use of Lingoes' method as an empirical validation procedure for curriculum hierarchies has been demonstrated by numerous researchers (e.g. Resnick and Wang, 1969; Boozer, 1970; Boozer and Lindvall, 1971; Wang, 1972).

This study will report on the application of this procedure to several units of the Individualized Mathematics Curriculum (1971). The Individualized Mathematics (IM) Program is based on the model described by Glaser and Nitko (1971). The curriculum, hierarchically constructed using "task analysis", is divided into units of instruction each of which is comprised of instructional objectives defined in terms of student behaviors. Both the units of instruction and the instructional objectives were arranged using this logical procedure.

It should be noted that the theoretical scales of the IM program are not necessarily "linear". In fact most are "branching". (See Figure 1) In the case of branching scales, the overall scale plus each path in the scale must be examined in order to validate the hierarchy.

During the application of the procedure developed in this study, refinements were made in it based primarily on feedback obtained from the developers through a series of interviews. The initially proposed procedure consisted of five general steps:

1. The curriculum developers order the curriculum objectives using a logical analysis (task analysis).
2. It is determined if tests already available examine students in those components of the curriculum structure to be validated. If not, such tests need to be constructed.

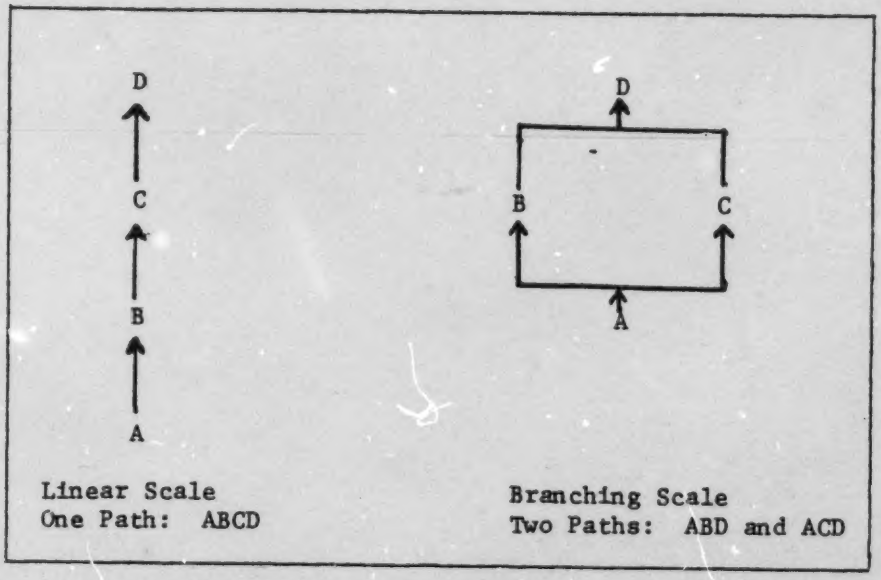

Figure 1. Examples of hypothetical linear and branching hierarchical scales for four curriculum objectives.

3. Using the test results, the developers apply multiple scalogram analysis to the sequences of objectives outlined in step one.
4. Meetings of the curriculum developers are held to discuss the results of the empirical validation procedure. Two possible recommendations arising from the comparison of the hypothesized and empirically generated hierarchies are:
   a) If the empirical evidence supports the theoretical structure, the validation is complete.
   b) If the theoretical structure is not supported, then (1) an alternative ordering of curriculum objectives is made or (2) the curriculum objectives are not reordered for logical or empirical reasons. That is, the results may be perceived by the developers as being completely contrary to learning theory and/or common sense and require further study before a final decision is made.
5. If the case were "a" above, no immediate reevaluation of the curriculum would be indicated. If, however, "b" were the case, retesting and another empirical analysis using multiple scalogram analysis (with or without curriculum changes) would be recommended for future developmental studies.

Research Population

The seventy-two students participating in this study were entering first grade pupils who were to be placed in the Individualized Mathematics program in two schools. One of the schools is a Pittsburgh inner city school

composed of predominantly black students, while the other school is located in the suburbs of Pittsburgh and consists of a Caucasian student body.

APPLICATION OF THE PROCEDURE AND RESULTS

The first step of the procedure required the developers to logically order the objectives of the IM curriculum. A portion (the first seven units) of this curriculum so structured was investigated in the research on which this paper is based (DiCostanzo, 1974). For the purposes of this paper, however, applying the procedure to two (the first two) of these units will suffice in illustrating its use. (See Figures 2 and 3)

The second step in the proposed procedure was to identify tests needed to measure pupil mastery of the objectives and units to be scaled. Because tests currently being used did not satisfy certain requirements of this study, the researcher was required to construct an additional test. Practical restrictions placed on the test required that it be usable with small groups of children (in contrast to individual students) and that it require a minimum amount of time. The test had to be an efficient measure of entrance behavior since the initial units of the curriculum were being examined.

The resultant instrument was a paper and pencil test that was to be used later as a placement test for the first units of the IM Curriculum. The intention was to measure student performances on each objective within these units. However, to enable a complete examination of the stated hierarchy, some objectives were not tested because of the practical restrictions listed above. When all of the objectives of a unit were not tested, those objectives to be included on the test were the higher level objectives

Individualized Math

Unit 1

Matching: More/Less

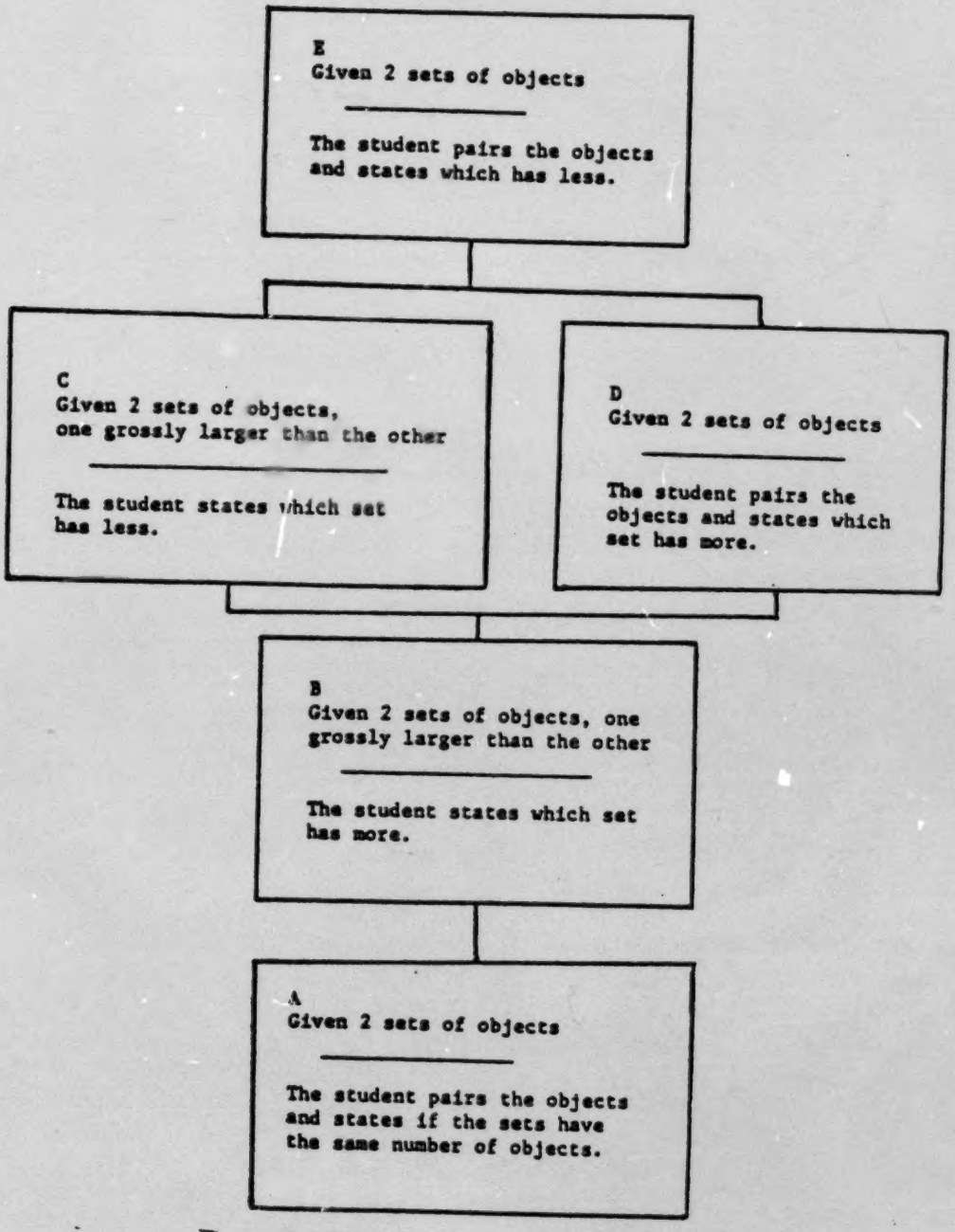
E
Given 2 sets of objects
The student pairs the objects and states which has less.
C
Given 2 sets of objects, one grossly larger than the other
The student states which set has less.
D
Given 2 sets of objects
The student pairs the objects and states which set has more.
B
Given 2 sets of objects, one grossly larger than the other
The student states which set has more.
A
Given 2 sets of objects
The student pairs the objects and states if the sets have the same number of objects.

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Figure 2. Hierarchy of Objectives in Unit 1 of the Individualized Mathematics Curriculum (1971).

Individualized Math

Unit 2

Seriation

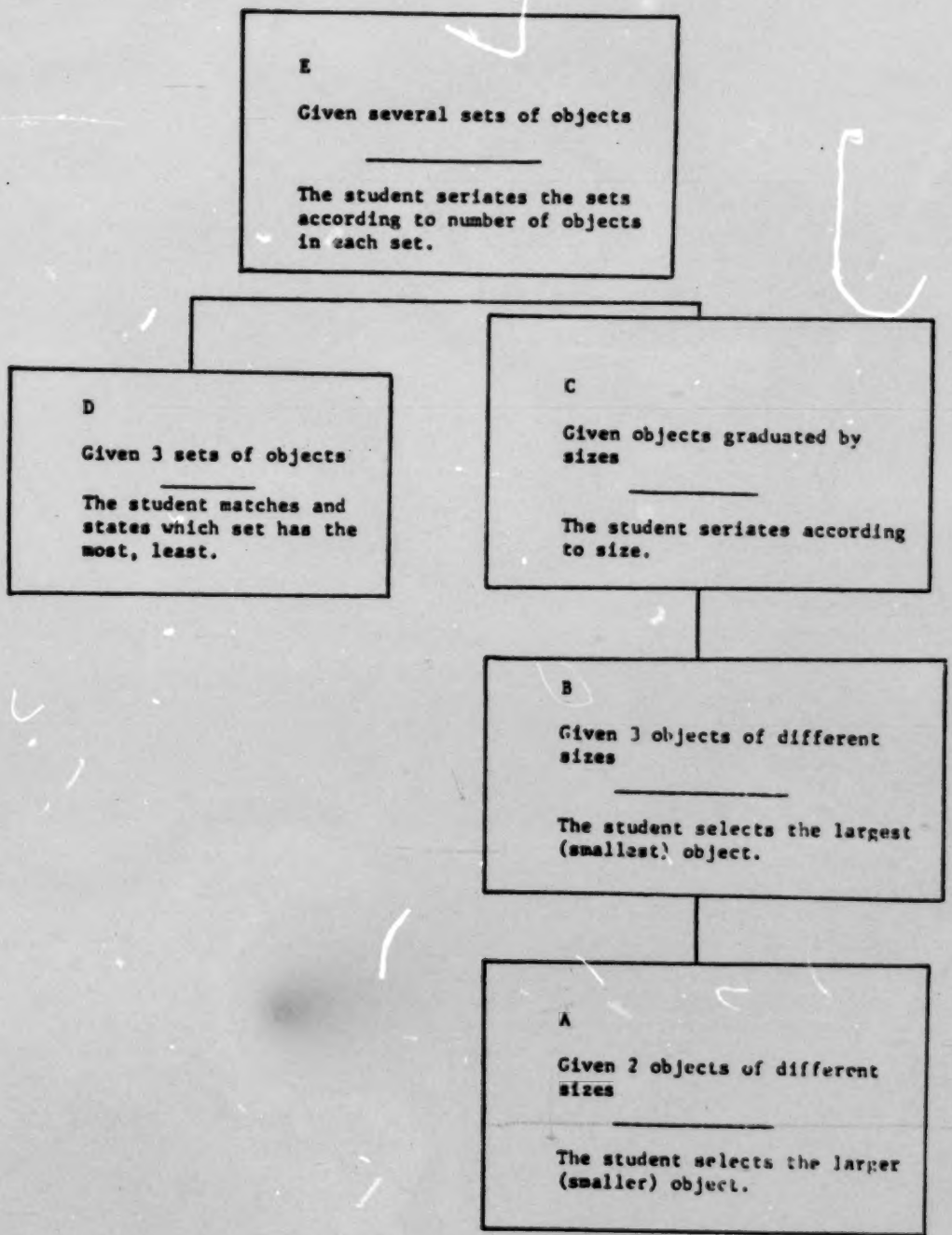
E
Given several sets of objects
The student seriates the sets according to number of objects in each set.
D
Given 3 sets of objects
The student matches and states which set has the most, least.
C
Given objects graduated by sizes
The student seriates according to size.
B
Given 3 objects of different sizes
The student selects the largest (smallest) object.
A
Given 2 objects of different sizes
The student selects the larger (smaller) object.

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Figure 3. Hierarchy of Objectives in Unit 2 of the Individualized Mathematics Curriculum (1971).

representative of all of the varied behaviors required of students in that unit (these always included the terminal objectives). The test, after try-outs and revisions, was then administered to the seventy-two entering first graders.

Multiple scalogram analysis was then applied to the test results. Two applications were usually necessary because as stated previously, most unit hierarchies are branching rather than being linear.

In accordance with steps four and five of the procedure, the results of the multiple scalogram analysis were examined by the curriculum developers

Unit 1

The original theoretical hierarchy for Unit 1 can be found in Figure 2. All of the objectives in this unit were tested. Initially multiple scalogram analysis was applied to all of the test items representing objectives in this unit to test if one linear scale existed among them. As can be seen in Figure 4 under the heading "Path ABCDE", three scales were produced. Objectives B and E formed a scale (B prerequisite to E) with a perfect (1.00) reproducibility coefficient; objectives D and A formed a scale (D prerequisite to A) with a reproducibility coefficient of .986; and objective C did not scale, i.e. it was not a part of the BE and DA scales.

Because a linear scale did not exist among all of the objectives, multiple scalogram analysis was applied to investigate paths ABCE and ABDE. The results of these separate analyses are found in Figure 4 also. The application to path ABCE revealed objectives B and E scaling again with the same reproducibility coefficient. Objectives A and C, however, did not scale. Two scales, objectives B and E, and objectives D and A, were the outcome of the multiple scalogram analysis application to the items representing the four objectives in path ABDE.

Path ABCDE			Path ABCE			Path ABDE	
Sc. 1	Sc. 2	Sc. 3	Sc. 1	Sc. 2	Sc. 3	Sc. 1	Sc. 2
E	A		E			E	A
B	D	C	B	A	C	B	D
1.00[1]	.986[1]		1.00[1]			1.00[1]	.986[1]

[1]Reproducibility coefficient for scale

Figure 4. Scales Derived from Multiple Scalogram Analysis for Unit 1.

Path C D E
E
D
C
.963[1]

[1]Reproducibility coefficient for scale.

Figure 5. Scale Derived from Multiple Scalogram Analysis for Unit 2.

Upon examining these results, the developers agreed that the concepts taught in Unit 1 needed to be reordered. The concept "more" would now be taught first; the concept "less" next; and, the concept "equal to" last. They concurred that multiple scalogram analysis should be reapplied in the following year in order to validate this major reordering.

Unit 2

Objectives C, D, and E were tested in Unit 2, (see Figure 3) as these represented the higher-level objectives of this unit. Multiple scalogram analysis was then applied to the test items representing these objectives in order to determine if a linear scale existed among them. Figure 5 shows that only a single linear scale (CDE) exists among these objectives. As a result, the separate paths of objectives (CE and DE) represented in the branching theoretical scale were not tested.

During their discussion of the above results, the developers revealed that the arrangement of Unit Two's objectives in the linear scale (CDE) was posited during the early design of the unit. They agreed to restructure this unit's hierarchy according to this result, thus enabling the empirical finding to aid in resolving their dilemma.

In addition, logical considerations based on the content of objectives A, B, and C and supported by the fact that objectives C, D, and E scaled, suggested to the developers that objectives A and B could possibly be eliminated altogether or that the learning activities for these units could be incorporated into those for objective C, making the unit more efficient. Two ways of examining the feasibility of this change were proposed: first, posttest data on objectives A and B would be examined, and second, an experiment to assess the need for the learning activities of these units

would be conducted. The first of these involves determining how many children actually worked in these units. If, for example, most children pretested out of these objectives, it would seem reasonable to incorporate the learning activities for these objectives, at least nominally, into those for objective C. The second method would include running an experiment to see if it would be necessary for objectives A and B to be taught at all in order to reach the unit's terminal objective (E). This experiment would compare a group of children who proceeded through objectives ABCDE and another group of children who would begin at objective C. They would be compared on their mastery of the material using a unit test, the time they need to complete the unit, and their retention of the material.

DISCUSSION AND CONCLUSIONS

This study investigated the application of a systematic procedure for validating the sequence and structure of curriculum hierarchies. The procedure used involved a combination of a logical analysis of the content and abilities being taught (task analysis) and an empirical analysis (multiple scalogram analysis) of the hierarchies as revealed by pupil test performance.

Two types of products were generated by this research, content-related (the modifications made to the Individualized Mathematics Curriculum) and procedural (refinements to the proposed procedure which integrates logical and empirical techniques for hierarchically structuring individualized curricula). It can be stated with regard to the first of these, that the developers found this application of the procedure to be a meaningful experience. The two major content-related results from the procedure's first application were the reordering of the three concepts taught in Unit 1 and

the restructuring of the hierarchy of objectives in Unit 2. From these results, it can be concluded that the procedure was valuable in aiding the curriculum developers maximize the effectiveness of the curriculum.

Although several revisions were made to it, the developers expressed their approval of its use. The expanded and revised procedure follows:

1. The curriculum developers review other curricula and literature related to the ordering of mathematical concepts contained in the portion of the curriculum under investigation. Utilizing this knowledge and a logical analysis of the content material, the developers structure this portion of the curriculum, possibly testing the structure of the objectives on individual students. The final curriculum hierarchy is a result of integrating all of this information.

2. The developers identify the requirements and restrictions that must be placed on the measure to be used in the study. They then examine curriculum tests already available with regard to the restraints listed. If no measure satisfies these requirements and restrictions, the developers construct a test to examine students working in that portion of the curriculum structure to be validated.

3. This test is administered to a group of students whose progress reflects the total portion of the curriculum being investigated. Using the test results, the developers apply multiple scalogram analysis to the sequences of objectives and units outlined in step 1.

4. Joint meetings of the curriculum developers are held to discuss the results of the empirical validation procedure. Two possible outcomes arising from the comparison of the hypothesized and empirically generated hierarchies are:

a) The empirical evidence supports the theoretical structure.

b) The empirical evidence does not support the theoretical structure. This may indicate a need for (1) reordering some of the curriculum objectives or (2) deciding not to reorder until further evidence is acquired.

5. If the case were "a", two possible recommendations may be suggested. First, the developers could accept these results and indicate that there is no need for further analysis, or second, they may see a need for additional analysis in the form of a well designed experiment or the testing of an additional sample of students with a subsequent reapplication of multiple scalogram analysis.

If the case were "b", a reapplication of multiple scalogram analysis with or without curriculum changes could be recommended or another type of empirical analysis, e.g. experiments, could be recommended.

6. Any alterations of the original curriculum structure, as well as applications of multiple scalogram analysis recommended for the future, should be dealt with through the reapplication of the validation procedure beginning with step 2. (This step is included to emphasize the iterative nature of any developmental effort.)

Finally, it is important to point out that the steps in the above developmental scheme are a part of a larger effort to delineate the steps in the development and evaluation of individualized curriculum hierarchies (see DiCostanzo, 1974). The expanded procedure includes a description of the evaluator's role in this process. This procedure serves not only the functions of the present paper but makes explicit all of the steps in the process of the development and evaluation of hierarchical curriculum structures.

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